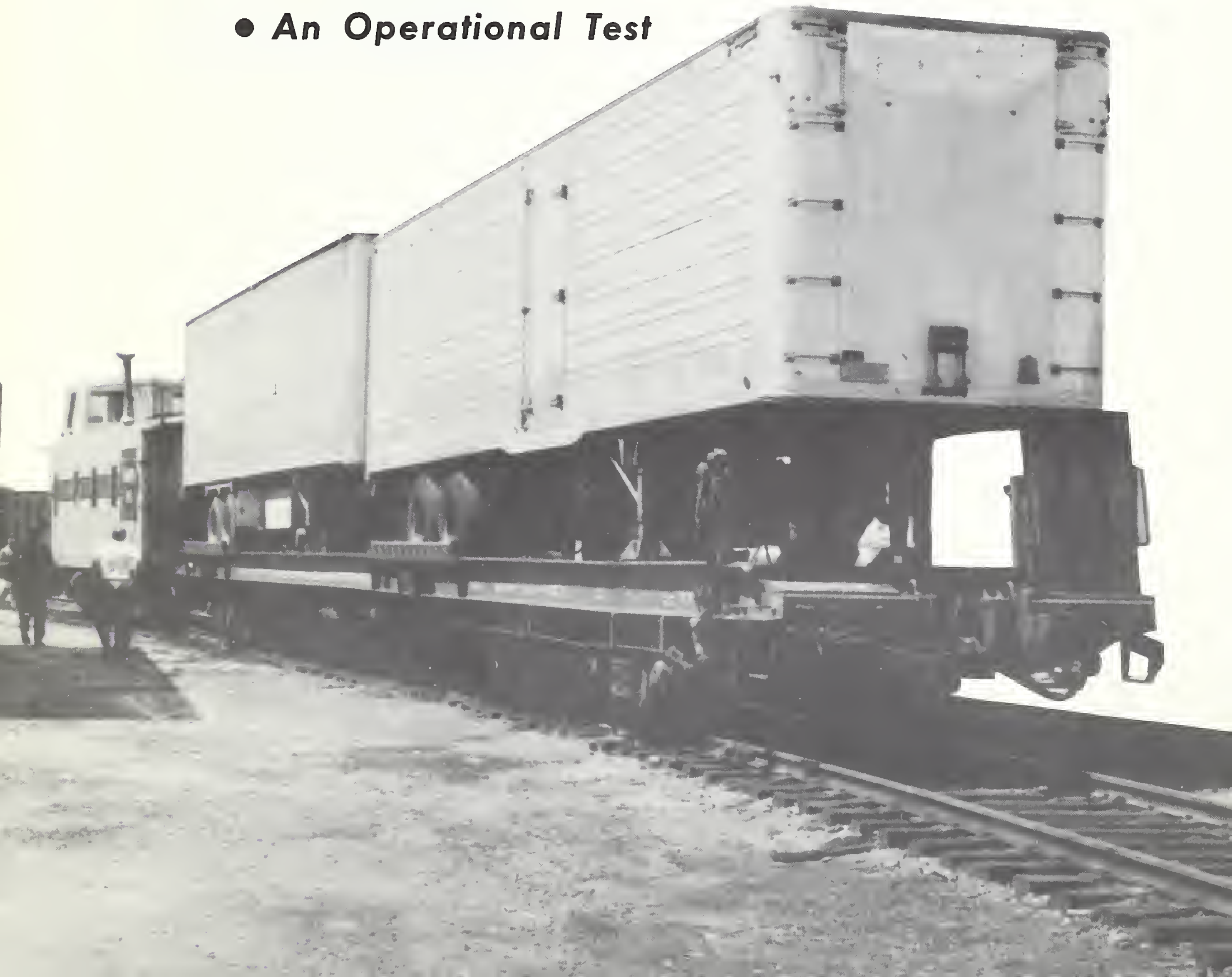
U. S. DEPARTMENT OF AGRICULTURE • Agricultural Marketing Service
Transportation and Facilities Research Division • AMS-522

Liquid Carbon Dioxide Refrigeration in a Frozen-Food Trailer

• An Operational Test



PREFACE

This study is part of a broad program of research to improve the design and performance of equipment for transporting agricultural products, as a means of increasing the efficiency of marketing farm commodities.

The test was made to evaluate the merits of liquid carbon dioxide refrigeration in transporting frozen food by truck-trailer as a possible improvement over mechanical refrigeration.

The following companies cooperated in the test: American Stores Company; Cardox Division of Chemetron Corporation; Burlington Refrigerator Express Company; Chicago, Burlington and Quincy Railroad Company; Fruit Growers Express Company; and Pennsylvania Railroad Company.

CONTENTS

SUMMARY

Mechanical refrigeration systems generally have performed well in truck-trailers transporting frozen food and have been a significant factor in the growth of that industry. However, the industry wants a refrigeration system with fewer breakdowns and lower maintenance costs.

The purpose of this test was to evaluate the use of liquid carbon dioxide (CO_2) for refrigeration and to determine its suitability for use in the transportation of frozen foods. A trailer with CO_2 refrigeration and a trailer with mechanical refrigeration were each loaded with 26,000 pounds of frozen meat and tested on a "piggyback" (trailer-on-flatcar) run between Pueblo, Colorado, and Philadelphia, Pennsylvania. U. S. Department of Agriculture research workers accompanied the trailers to obtain data. Meat and air temperatures in each trailer were read every 3 hours by means of thermocouples connected to an electronic temperature indicator located in the caboose.

Both trailers maintained about the same average commodity temperature, with the CO_2 refrigerated trailer generally at 3° F. and the mechanically refrigerated trailer at 1° F. However, an overall evaluation of the test indicates that the CO_2 refrigeration system has the following disadvantages at present:

When fully charged with liquid CO_2 it weighs 500 pounds more than the mechanical system;

It costs $138 more per trip to operate than does the mechanical system;

Loading crews cannot enter the trailer until CO_2 gas has been vented from the trailer for several minutes;

On a 6½-day trip the CO_2 system must be recharged several times, whereas the mechanical unit can operate on one tank load of diesel fuel; and

Liquid carbon dioxide is available at only a limited number of places, both on and off the rail line, while diesel fuel is widely available.

There are now on the market 40-foot trailers with a reported heat transmission of only 5,000 B.t.u. per hour and body designs will undoubtedly be improved further. More efficiently designed trailer bodies of the future will require less refrigeration and consumption of CO_2 will be correspondingly lower. If this trend continues, liquid carbon dioxide should compare more favorably with mechanical refrigeration.

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LIQUID CARBON DIOXIDE REFRIGERATION IN A FROZEN-FOOD TRAILER
-AN OPERATIONAL TEST-

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INTRODUCTION

Truck-trailers used for transportation of frozen foods which should be held at no higher than 0° F. are refrigerated almost exclusively by mechanical systems. These mechanical units generally have performed well in transport service and are certainly one of the major factors in the growth of the frozen-food industry. However, carriers have indicated a desire for a refrigeration system that would require less maintenance and have fewer breakdowns than is usual with mechanical equipment.

Recently several manufacturers have developed refrigeration systems which use liquid carbon dioxide (CO_2) or liquid nitrogen for cooling. Carriers, shippers, and receivers have shown great interest in these units and the industry wants more information about the use of such refrigerants. This report describes an in-transit test of a trailer refrigerated with CO_2 and loaded with frozen food on a "piggyback" (trailer-on-flatcar) trip between Pueblo, Colorado, and Philadelphia, Pennsylvania. The purpose of the test was to evaluate the ability of the CO_2 unit to maintain proper temperature, to measure its operating cost, and to determine its general suitability for transport application. A conventional mechanically refrigerated trailer was included in the test for comparison.

DESCRIPTION OF EQUIPMENT

Trailer A, with Experimental Refrigeration

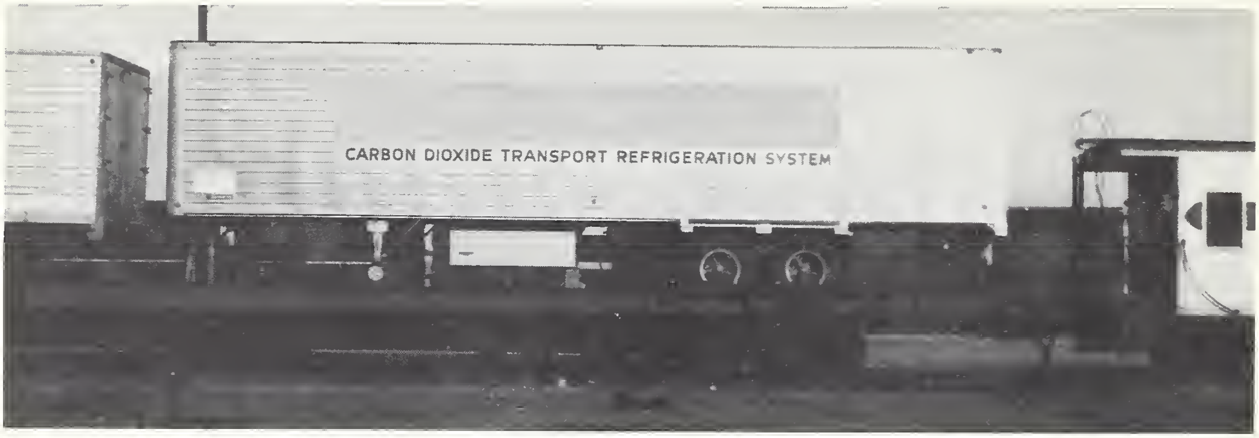

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Figure 1.--Trailer A on flatcar. Arrow indicates underslung liquid CO_2 tanks.

Trailer A, shown in figure 1, was a conventional trailer in all respects except for its experimental liquid CO_2 refrigeration system. Inside body dimensions were 39 feet long by 7 feet 4 inches wide by 7 feet 2½ inches high, with a cargo space of 2,060 cubic feet. Insulation was foamed-in-place (formed in the insulated spaces) polyurethane, 4 inches thick in the floor, walls, and ends, and 5½ inches thick in the ceiling. The trailer body had a reported heat transmission rate of 7,350 B.t.u. per hour at 100° temperature differential.

The cold gas was circulated inside the trailer by means of natural convection rather than by the usual method of forced air circulation using blowers. Space for air circulation around the load was provided by vertical strips 3/4-inch deep and 9 inches apart on the sidewalls, door, and front end of the trailer. Air space under the load was provided by corrugated floor grooves running lengthwise of the trailer which were 1 inch deep by 1¼ inches wide at the top by 7/8-inch wide at the bottom. These grooves were spaced 2 5/8 inches apart and all the floor grooves together provided a total of 35 square inches of cross section space for air circulation.

The manner in which the experimental refrigeration system operated is shown in figure 2. Four liquid CO_2 storage tanks, each of 500 pounds' capacity, were mounted in an insulated box under the trailer. A temperature sensing element inside the trailer activated a controller, which controlled the flow of CO_2 vapor at 35 pounds' pressure to a discharge nozzle at the ceiling. The vapor pushed the nozzle to the "On" position, and the liquid CO_2 at 0° F., forced up from the tank at 300 pounds' pressure, was discharged into the trailer. When the temperature sensing element reached the required inside temperature, the controller released the vapor, and the nozzle switched to the "Off" position.

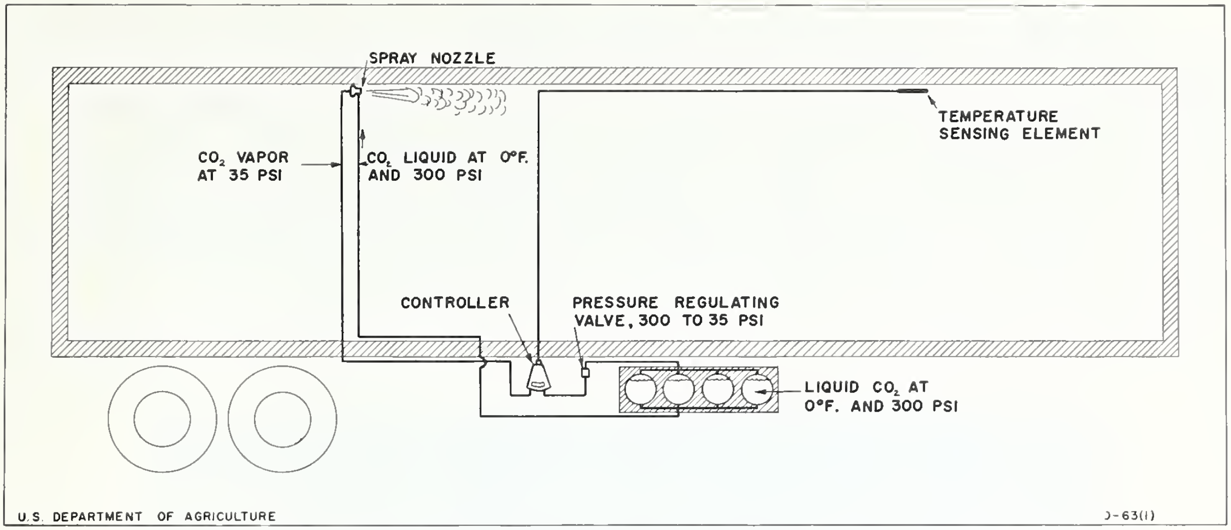

Figure 2.--Schematic diagram of liquid CO_2 refrigeration system in Trailer A.

Trailer B, with Conventional Refrigeration

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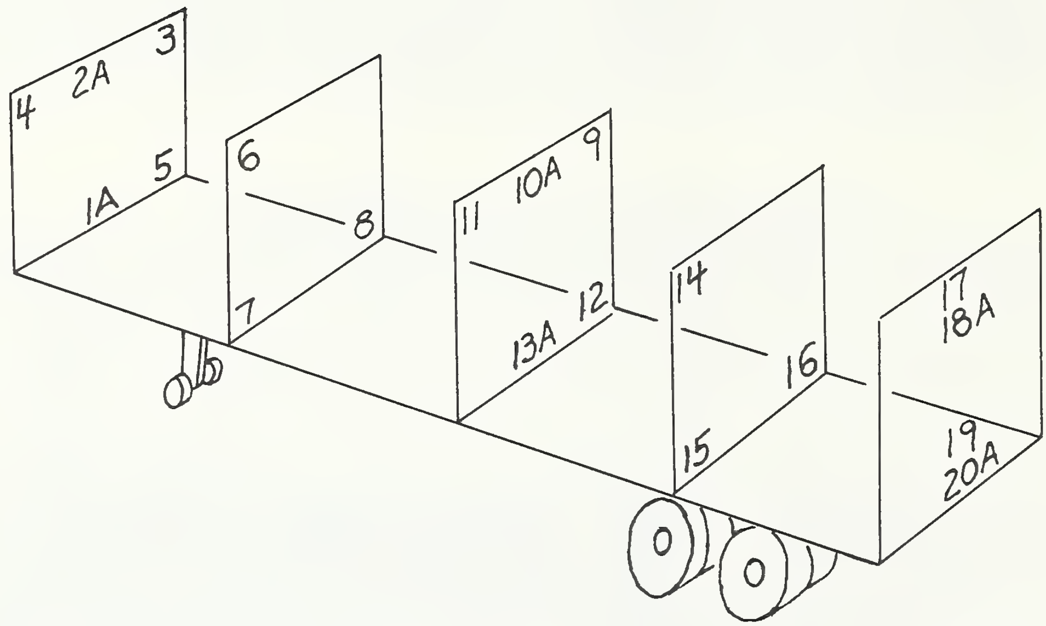
Figure 3.--Trailer B on flatcar.

Trailer B (figure 3) had a conventional body and mechanical refrigerating system. Inside body dimensions were 37 feet 6 inches long by 7 feet 3 inches wide by 6 feet 11 inches high, with a loading space of 1,880 cubic feet. Insulation materials and thicknesses were: 5-inch urethane blocks and 1-inch of glass fiber in the roof; 4-inch urethane blocks in the front and sidewalls; and 5-inch of urethane blocks in the floor.

Air circulation space around the load was provided by vertical strips similar to those in trailer A but spaced 8 inches apart. Air space under the load was provided by T-shaped grooves which were 2 inches deep on 2-1/8 inch centers. These grooves provided a total of 120 square inches of cross section space for air circulation.

The mechanical refrigeration system featured a four-cylinder water-cooled diesel engine and condenser mounted underneath the trailer with the evaporator inside the front of the trailer. The fuel tank had a capacity of 100 gallons. Cold air was distributed over the top of the load by six ducts made of neoprene-coated nylon that were mounted between the meat rails. The ducts were of various lengths. The two longest ducts delivered air to a point 1 foot 3 inches from the rear door; the two medium-length ducts delivered air to a point 11 feet 6 inches from the rear door; and the two shortest ducts delivered air to a point 21 feet 6 inches from the rear door.



No.	Location	No.	Location
1A	Front, bottom, center, air	11	½ length, top, left side
2A	Front, top, center air	12	½ length, bottom, right side
3	Front, top, right side	13A	½ length, bottom, center air
4	Front, top, left side	14	3/4 length, top, left side
5	Front, bottom, right side	15	3/4 length, bottom, left side
6	¼ length, top, left side	16	3/4 length, bottom, right side
7	¼ length, bottom, left side	17	Rear, top, center
8	¼ length, bottom, right side	18A	Rear, top, center air
9	½ length, top, right side	19	Rear, bottom, center
10A	½ length, top, center air	20A	Rear, bottom, center air

Note: All are commodity temperatures except those designated "A" which are air.

Figure 4.--Locations at which temperatures were taken in trailers.

TEST PROCEDURE

During loading, thermocouple wires were inserted into packages of frozen meat in each trailer at the positions shown in figure 4. Twenty thermocouples in each trailer were used to measure 14 product and 6 air temperatures. Trailer A was loaded with 1,624 boxes of packaged frozen meat that had a gross weight of 30,015 pounds and a net weight of 26,357 pounds. Trailer B was loaded with 1,601 boxes that had a gross weight of 29,762 pounds and a net weight of 26,150 pounds. Figure 5 and 6 show each trailer after loading had progressed to the halfway point in the trailer. After loading was completed the thermostats of both trailers were set at 0° F.

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Figure 5.--Interior view of trailer A showing loading completed to halfway point in trailer.

During the trip temperatures were read every 3 hours by means of an electronic temperature indicator located in a caboose behind the two trailers. The accuracy of the temperature indicator was checked each time by means of an ice bath at a temperature of 32° F.

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Figure 6.--Interior view of trailer B showing loading completed to halfway point in trailer.

TEST RESULTS

Temperatures

A record of the temperatures obtained for the two trailers during the test is shown in figure 7 and 8. Trailer air temperatures "Above Load, Average" were found by taking the average of temperatures 2A, 10A, and 18A (see figure 6). Trailer air temperatures "Below Load, Average" were found by taking the average of temperatures 1A, 13A, and 20A. (In trailer B, thermocouple 2A was in the air blast and therefore not used. Thermocouple 18A in this trailer did not function).

In trailer A, with the experimental CO_2 refrigerating equipment, average commodity temperature during the trip varied from -6^{o} F. to 6^{o} F., the maximum varied from 4^{o} F. to 18^{o} F., and the minimum varied from below -15^{o} F. to 0^{o} F. Maximum temperatures were found at positions 5 and 19 next to the trailer floor and minimum temperatures occurred at positions 6 and 11 on top of the load. The spread between maximum and minimum temperatures averaged 14 degrees during the trip.

Trailer air temperatures and commodity temperatures in trailer A seemed to fluctuate with outside air temperatures, at least during the first half of the trip. This would indicate that function of the control system was influenced by outside air temperatures. Toward the end of the test, at 6 p.m.

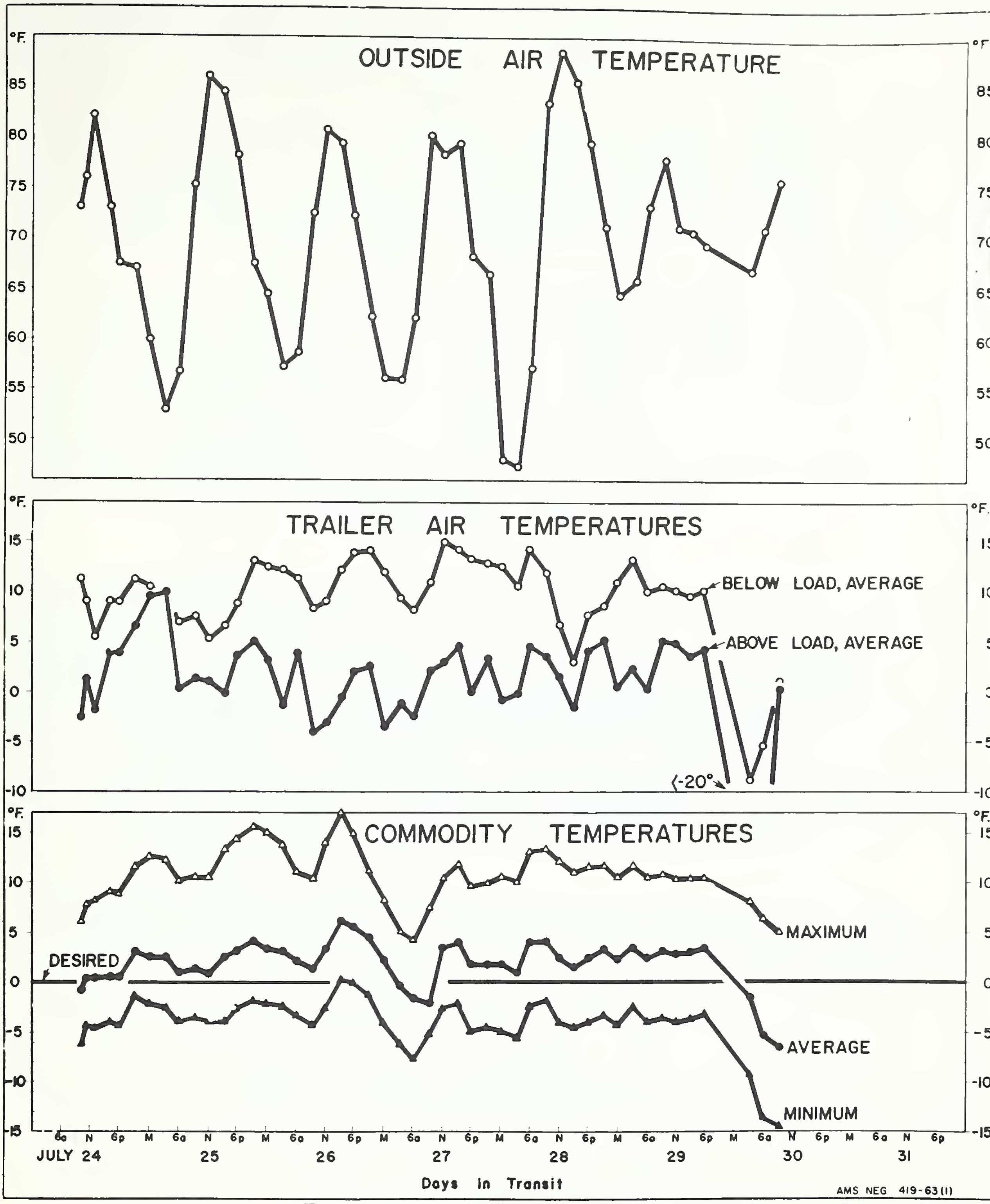

Figure 7.--Air and commodity temperatures in trailer A.

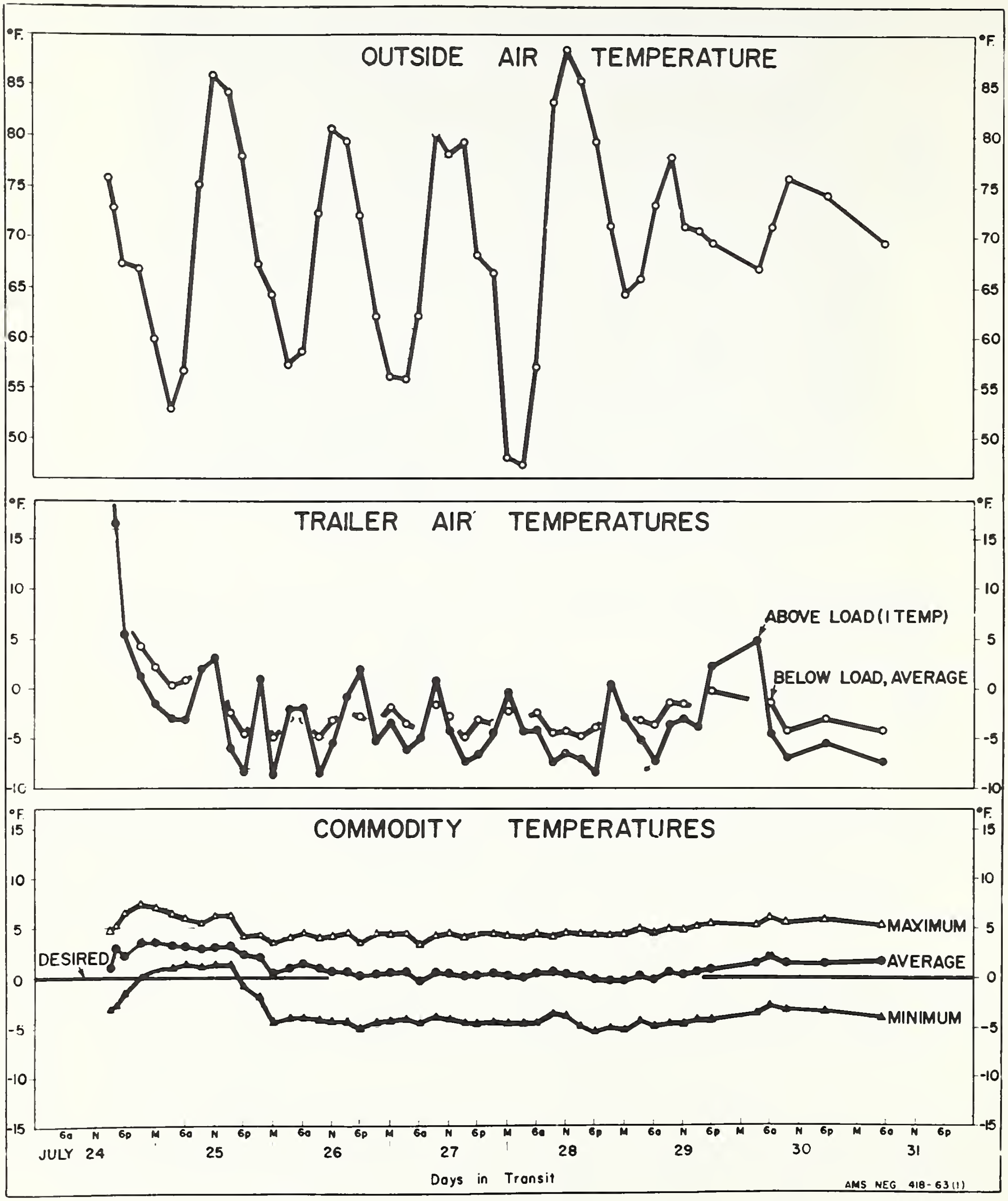

Figure 8.--Air and commodity temperatures in trailer B.

on July 29, the control stuck in the "On" position for a period of about 9 hours, causing temperatures to dip. The control was repaired and apparently operated normally thereafter.

In trailer B, with the conventional mechanical refrigerating equipment, the average commodity temperature varied from 0° F. to 4° F., the maximum varied from 3° F. to 7° F., and the minimum varied from -5° F. to 1° F. Maximum temperatures occurred at point 8 next to the trailer floor and minimum temperatures were found at positions 3 and 4 on top of the load. The spread between maximum and minimum temperatures avaraged 8 degrees during the trip.

The smaller spread of 8 degrees in commodity temperature in trailer B as compared to 14 degrees in trailer A possibly was caused by differences in air space under the load. Trailer A had only 35 square inches of cross-sectional area under the load while trailer B had 120. The more air space available for air circulation the smaller should be the temperature spread. Therefore, this difference in performance between the two trailers should not necessarily be attributed to differences in the refrigerating systems.

CO_2 and Fuel Consumption

Trailer A required 8,921 pounds of liquid CO_2 for a 166.5 hour period including initial filling and six refillings of the tanks enroute. At the completion of the test, 625 pounds of CO_2 remained in the tanks; net consumption was 8,296 pounds. As mentioned previously, the control of the CO_2 unit stuck on the "On" position at 6 p.m. on July 29, causing higher than normal fuel consumption for the next 9 hours. Until a refilling of the tanks at 7 p.m., the unit had operated 129.5 hours, consuming 5,481 pounds of CO_2 for an average of 42.3 pounds per hour. For the remaining 37 hours of the test the fuel consumption was 2,815 pounds--an average of 76.1 pounds per hour. The hourly consumption figure of 42.3 is considered more appropriate to use when comparing the costs of the CO_2 unit and the mechanical unit because of the 9-hour malfunction.

Trailer B did not require refueling during the 158.5 hour test period and consumed 65 gallons of diesel fuel for an average of .41 gallons per hour.

In comparing out-of-pocket costs a test period of 158.5 hours is used for both refrigerating units. For the CO_2 unit an hourly consumption of 42.3 pounds gives a total use of 6,704 pounds. Based upon the manufacturers estimate of 3¢ per pound for large volume usage, the cost of CO_2 for the trip was $201.12. The cost of diesel fuel at 20¢ per gallon for 65 gallons amounted to $13.

Comparative Weights and Costs

The CO_2 system in trailer A weighed 3,200 pounds: 1,200 pounds of equipment and 2,000 pounds of liquid carbon dioxide when tanks were filled to capacity. The weight of the mechanical system in trailer B was 2,700 pounds, including 2,000 pounds of equipment and 700 pounds of diesel fuel when tank was filled to capacity. Thus the liquid CO_2 system weighed 500 pounds more than the mechanical system.

Table 1 is a comparison of the per-trip cost of each system. Initial cost and installation figures, obtained from cooperators in the test, were about the same for both systems: $3,980 for the CO_2 unit, and $3,900 for the mechanical unit. The CO_2 equipment, because of its simplicity and few moving parts, should remain in operating condition for many years. However, because of expected obsolescence, depreciation was figured on a 10-year basis at $398 per year. Assuming 18 trips per year gives a per-trip depreciation of $22. Depreciation for the mechanical system was figured similarly, except on a 5-year basis, at a per-trip depreciation of $43.

Table 1.--Per-trip (158.5 hours) cost comparison of the CO_2 and mechanical refrigeration systems, assuming 18 trips a year

Item	Trailer A (CO_2)	Trailer B Mechanical
	Dollars	Dollars
Depreciation	22	43
Maintenance	0	29
CO_2 or diesel fuel used	201	13
Total cost (items 1, 2, 3)	223	85
CO_2, greater cost per trip	138	

Maintenance costs for the CO_2 unit should be negligible. The maintenance costs for the mechanical unit are estimated to vary from $350 for the first year to $700 for the fifth year--an average of $525 per year. Assuming 18 trips per year per-trip maintenance cost would be $29.

CONCLUSIONS

Average commodity temperatures in the two trailers were approximately the same. The spread between maximum and minimum temperature throughout the trip was greater in the CO_2 refrigerated trailer than in the mechanically refrigerated trailer. However, much of this difference probably occurred because trailer A had less air circulation space under the load than did trailer B.

The CO_2 refrigeration unit appears to have the following disadvantages at the present time: When fully charged with liquid CO_2 it weighs 500 pounds more than the mechanical unit does when its tank is filled with diesel fuel; it costs $223 per 6½-day trip as compared to $85 for the mechanical unit, or a difference of $138; CO_2 gas must be removed from the trailer before loading crews can enter; for a 6½-day trip the CO_2 unit requires several rechargings enroute compared to no refueling requirements for the mechanical unit; and liquid CO_2 is not now as widely available as diesel fuel.

The 35-foot trailer body refrigerated by CO_2 had a reported heat transmission rate of 7,350 B.t.u. per hour, at 100° temperature differential, in a previous test made by the cooperator. There are now on the market 40-foot trailers with a reported heat transmission rate of only 5,000 B.t.u. per hour and no doubt body designs will be improved further. More efficiently designed trailer bodies of the future will require less refrigeration and consumption of CO_2 will be correspondingly lower. If this trend continues, liquid carbon dioxide should compare more favorably with mechanical refrigeration.